Geometric Design and Other Characteristics Affecting Operating Speeds On Gravel Roads

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ABSTRACT

In the United States, there are nearly 1.6 million miles of unpaved roads, which approximately represent about 53% of all roads and consist mainly of gravel roads. Even though such gravel roads carry low volumes, they provide an invaluable service to the mobility and transportation needs of people living in rural areas. Operating speed on the other hand is extremely important for any type of a roadway. Even though speed limits of gravel roads are typically set based on statutory guidelines there are some instances where exceptions are in place. Other characteristics of gravel roads also vary significantly across gravel roads.

Accordingly, the objective of this study was to evaluate various factors affecting the operating speeds on gravel roads. Field speed data were collected at number of sites located in the state of Kansas using automatic traffic data counters. Based on the speed data collected, comparisons were made based on various characteristics and simple linear regression models were developed to predict 85^{th} speed and the mean speed of vehicles on gravel roads. The factors looked into and evaluated in this study include surface type, roadway width, speed limit, and percentage of heavy vehicles.

Results of this study indicated that the 85^{th} percentile speeds on gravel roads are affected by surface type, road width, and the percentage of heavy vehicles. Interestingly the speed limit was not a predictor of the operating speeds on gravel roads. Lowered posted speed limit values on gravel roads have also not helped in reducing operating speeds, but have increased the number and percentage of speed limit violators.

INTRODUCTION

Gravel roads pay a major role in providing mobility in rural areas and consist of a large proportion of the rural road network, particularly in relatively rural states. Based on year 2005 data, gravel roads accounted for about 78.5% of total rural road mileage in Kansas *(1)*. Safety on gravel roads also appear to be of significant importance in states like Kansas, even though they carry relatively small traffic volumes. During the 10-year period from 1996 to 2005, a total of 433 fatal crashes were reported on Kansas gravel roads, which resulted in 478 personal fatalities *(2)*. This accounted for about 10% of the total number of fatalities due to motor vehicle crashes in Kansas during that time period.

As widely accepted, speed limits play a very important role in improving traffic operations and safety, making it necessary to set speed limits properly on all different types of roadways. Even though there have been significant amount of studies and body of knowledge established in the area of setting speed limits on roadways of higher functional classifications and paved roadways, there do not seem to be a whole lot of studies focused on speed limits on gravel roads. There is no uniformity among states in setting speed limits on local roads *(3)*. As of 2001, 26 states used 55 mph as the regulatory speed limit on local roads, while 24 states used different criteria.

While there certainly are differences in speed limit criteria among states, there could be differences even within a state. For example, speed limit on gravel roads in Kansas is regulated at 55 mph as per the Kansas Statutes *(4)*, which is not typically posted or frequently enforced. However, within the guidelines provided in the Statutes, there are some counties where speed limits are reduced to substantial levels (35 mph and 45 mph) and also posted throughout gravel roads. These changes have been expected to provide a safer driving and living environment for gravel road users and rural residents. However, effectiveness of such changes is still needed to be evaluated so that future recommendations could be made in relation to new situations of similar nature.

While speed limit is typically expected to be strongly related with the operating speeds, there could be many other geometric and other parameters affecting operating speeds of gravel roads. If these factors could be identified it could be possible to establish a more uniform approach to select the appropriate speed limit for gravel roads.

OBJECTIVES

The main objectives of this study are (1) to evaluate the effects of speed limits on actual operating speeds of vehicles on gravel roads; and (2) to evaluate various factors affecting the operating speeds on gravel roads.

LITERATURE REVIEW

Limited number of gravel road related studies that have been completed in the past is briefly discussed in this section.

In Michigan, the State Police researched and developed criteria for correlating the appropriate speed limit to the number of access points on gravel roads. A law was approved in 2006, which allows local road agencies to establish “prima facie speed limit” on gravel roads based on the number of access points per mile, i.e., 25 mph on a road segment with 60 or more access points within 0.5 mile, 35 mph on a road segment with 45 to 59 access points within 0.5 mile, 45 mph on a road segment with 30 to 44 access points within 0.5 mile *(5)*. Another bill was passed on June 2007 in the Michigan Senate to allow the local government in Oakland County to post gravel or dirt roads, which were previously posted with 25 mph signs, with lower limit signs than the 55 mph "prima facie" speed limit on the basis of the number of residences on the road, regardless of whether it is paved *(6)*.

An extensive online search found that a number of local jurisdictions do not think the use of speed limits on gravel roads is practical due to the easily changeable surface conditions of gravel roads. For example, Franklin Regional Council of Governments (FRCG) in Massachusetts indicates that an ideal speed limit on gravel roads should be both acceptable to prudent drivers and enforceable by police departments and that gravel roadways are not typically speed zoned due to the fact that it is impossible to establish a consistent road surface and conditions on gravel roads which tend to change over a relatively short period of time *(7)*. Minnesota Department of Transportation (Mn/DOT) states that "*gravel roads are designed with minimal design criteria, are subject to fluctuating surface conditions, have low enforcement priority, and serve low ADT's usually comprised of local repeat traffic*", therefore Mn/DOT has generally not set speed limits on gravel roads *(8)*. Jackson County of Oregon indicates that no speed zone is used on gravel roads because Oregon Department of Transportation (ODOT) feels that conditions on gravel roads vary too much for a specific speed limit to be appropriate *(9)*. The Road Commission in Livingston County, Michigan, also indicates that they only consider posting a speed limit on a gravel road if it meets the criteria specified for prima facie speed limits and absolute speed limits are not considered due to the continuously changing conditions of gravel roadways *(10)*.

In Australia, the Department of Infrastructure, Energy and Resources (DIER) indicated that speed limit signs are not installed on unsealed roads (dirt or gravel) as it may imply that there is a safe speed at which motorists should travel on such roads *(11)*. Whereas, motorists should be aware that the actual safe speed of travel on unsealed roads may vary tremendously within a short space of both time and distance due to weather or road conditions. Based on the thinking of DIER, motorists should be responsible for assessing prevailing weather and road conditions and their own abilities in order to determine an appropriate safe driving speed on unsealed roads.

A speed study was conducted in Oakland County, Michigan, in 1990, which was aimed at studying the effectiveness of residential 25 mph speed limits on both local and primary gravel roads *(12)*. The 85th-percentile speed was 36.75 mph on posted local roads, and 36.21 mph on unposted local roads, which were virtually identical. On primary roads, the 85th percentile speed was 42.72 mph on posted roads and 45.42 mph on unposted roads, which was found to be significantly different at 99% confidence level based on the Z-test. In real terms, the difference of 2.7 mph does not mean a noticeable change to the average driver or resident. This study indicated that it was hard to conclude that the 25 mph residential speed limit on gravel roads had affected driver behavior and that this speed limit served no purpose other than as a 'placebo' to the residents of the affected roadways.

Another study indicated that speed limits should not be established on unpaved roads as roadway characteristics such as terrain, surface conditions, geometric alignment, and sight distance may combine as positive guidance to dictate the safe speed of an unpaved road *(13)*. Posting inappropriate signs might breed disrespect for all signs. It was advised to regulate speeds using measures other than speed limit signs in those instances where safe speeds can vary with changing roadway conditions and where road characteristics help regulate speed.

METHODOLOGY

The objectives of this study were achieved by collecting and analyzing actual speed data on a number of gravel road sections. In addition to speed data, other details such as type of the gravel road surface, width of the road, speed limit criteria, traffic volume, and percentage of heavy vehicles were also obtained. Methodologies used in collecting speed data and analyzing the collected data, are described in this section.

Data Collection

In this study, two sets of JAMAR TRAX I Plus automatic traffic counters were used for the speed data collection. Each set consists of a traffic counter, two half round or D-shaped pneumatic tubes and accessories. Figure 1 shows the standard setting up of the traffic counter, where the spacing between the two tubes is eight feet. Two ends of the tubes on one side are fixed on the shoulder, and the other two ends are connected to the traffic counter. When a vehicle passes over the tubes, air pulses are sent to the counter and two time stamps are recorded in the counter as raw data, which are analyzed with special analysis software (TRAXPro) provided by the manufacturer to produce the output of speed measurements. The output consists of a combination of speed values, including mean speed, pace, and 85th-percentile speed. Other related traffic information including Average Daily Traffic (ADT), vehicle classification distribution, percent of vehicles exceeding speed limit are also provided. The automatic traffic counters are well designed for data collection on low-volume gravel roads since they can work in the field for a long duration without needing much attendance. The duration of data collection was usually one week at each site, subjected to minor changes based on weather and traffic conditions.

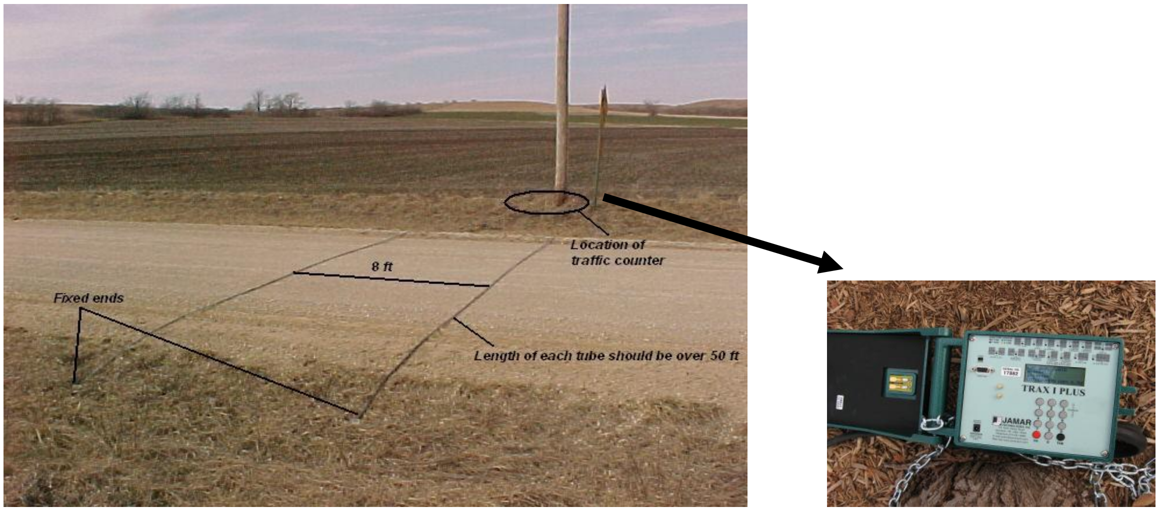

FIGURE 1 Setting up of the traffic counter

For comparison purposes, gravel roads are classified into three groups, labeled here as G1, G2 and S, as shown in Figure 2, based on the amount of gravel on the surface. A surface with a smaller amount of gravel is coded as "G1", a surface having a large or moderate amount of gravels or crushed rocks is coded as "G2". The code of "S" denotes those gravel roads with sand surfaces as shown in Figure 3(c). This classification is based on subjective observations at the time of data collection and is prone to change from time to time, depending on the grading work carried out by maintenance personnel.

(a) G1 (b) G2 (c) S

FIGURE 2 Description of gravel surface classifications.

RESULTS & ANALYSIS

Summary of the operational speed observations on gravel roads is given in Table 1. Except for the sites on Sedgwick and Johnson counties, majority of the sites represent the frequently used 55 mph regulatory speed limit on gravel roads, which is not normally posted. Review of those sites indicates that almost all such sites with gravel surfaces are operating at reasonable levels with 85th percentile value hardly exceeding 55 mph.

Operating Speed Comparisons based on Speed Limit Criteria

As indicated in Table 1, Johnson County employs different gravel road speed limit criteria where the speed limit of 35 mph is posted on gravel roads similar to the way they are posted on paved roadways. Nearby Miami County gravel roads have very similar characteristics, but use the 55 mph statutory speed limit criteria. The K-S test results indicated that the p-values for each data set were greater than 0.05, confirming speed data fitted normal distribution. Accordingly comparisons were made using Two-sample t-tests as follows:

1) Test the difference between the mean speeds of Johnson and Miami Counties, which are adjacent counties and use different speed limit criteria (Johnson County sets 35 mph speed limit signs on all gravel roads while Miami County does not).
2) Test the difference between the mean speeds of Johnson County and a combination of Miami, Shawnee and Riley Counties, which have similar road-surface characteristics but different speed limit criteria.

The t-test results are presented in Table 2, which shows that the p-value is very small, indicating the mean speeds of these two counties were significantly different at 95% level of confidence. In other words, the 37.5 mph mean speed of Johnson County is significantly higher than the 35.8 mph mean speed of Miami County. This finding is astonishing since Johnson County has a lower speed limit that is posted on gravel roads while Miami County has the statutory speed limit of 55 mph, which is not posted. General expectation is that the mean speed should be lower when the speed limit is lower. However, the results indicate the reverse of the expected situation. This might be interpreted as that the motorists in some cases neglect the posted speed limit signs and judged their speeds based on other features like roadway conditions.

The p-value for the second t-test comparing Johnson County to other three counties is 0.4154, which implies that there is no evidence that the mean speed of vehicles in Johnson County is different from that of the other three counties. Accordingly, the interpretation is that when gravel roads with different speed limits have similar roadway, surface, and geometric conditions, the mean speeds do not change significantly.

Table 2 Comparison of Mean Speeds based on Speed Limit Criteria

Test	County	Sample Size	Mean (mph)	Standard Deviation (mph)	F-test for Equality of Variances		t-test	
					F-value	p-value	t-value	p-value
1	Johnson	2,665	37.5	8.6	1.15	0.0008	6.10	< 0.0001
	Miami	1,868	35.8	9.2				
2	Johnson	2,665	37.5	8.6	1.45	<0.0001	-0.81	0.4154
	Combined	9,334	37.6	10.4				

General Relationships

In order to better understand the relationships between the operating speed and various other factors each was plotted separately as shown in Figures 3 through 5. It was noted that the width of the road, surface type, and percentage of heavy vehicles are related with operating speeds on gravel roads.

TABLE 1 Summary of Speed Characteristics on Gravel Roads in Kansas

ID	County	Location	Surface Classification	Road Width (ft)	Speed Limit (mph)	ADT (veh/ Day)	Percentage of Heavy Vehicles	**85th-Percentile Speed**	Mean Speed (mph)	Pace (mph)	Percentage in Pace Speed	Percentage Exceeding Speed Limit
1	Riley	Marlatt Ave	G2	24	55	47	18.6%	**45**	38	36-45	57.6%	0.0%
2	Riley	Riley 424	G2	24	55	72	45.8%	**46**	36	26-35	55.6%	0.0%
3	Riley	Riley 911	G2	26	55	52	37.8%	**58**	49	41-50	48.6%	23.4%
4	Riley	Riley 422	G2	24	55	69	20.9%	**53**	44	41-50	45.2%	6.5%
5	Riley	Riley 428	G2	24	55	95	4.7%	**44**	36	31-40	54.3%	0.5%
6	Riley	Tabor Valley(S/N)	G2	24	55	38	19.0%	**53**	43	41-50	45.0%	10.3%
7	Riley	Tabor Valley (E/W)	G2	24	55	37	15.8%	**50**	43	39-48	47.4%	5.2%
8	Riley	Fairview Church #1	G1	24	55	55	19.0%	**49**	37	36-45	43.8%	4.1%
9	Riley	Fairview Church #2	G1	24	55	24	18.2%	**49**	39	31-40	47.7%	9.1%
10	Riley	Alembic Rd	G2	24	55	46	15.8%	**53**	44	41-50	40.3%	9.3%
11	Riley	N 60th St	G1	22	55	37	19.4%	**50**	41	34-43	40.7%	2.4%
12	Riley	Walsburg Rd	G2	24	55	67	19.3%	**57**	46	46-55	37.9%	18.8%
13	Riley	LK&W Rd	G2	20	55	20	11.9%	**44**	37	31-40	53.0%	0.0%
14	Riley	N 52nd St	G1	20	55	91	35.2%	**44**	34	31-40	38.2%	0.0%
15	Riley	Rocky Ford Rd	G2	22	55	179	10.7%	**35**	29	21-30	51.2%	0.5%
16	Riley	Kitten Creek Rd	G2	22	55	34	7.1%	**40**	34	31-40	50.0%	0.0%
17	Riley	Silver Creek Rd	G1	16	55	25	16.2%	**48**	40	31-40	52.0%	3.1%
18	Riley	W 59th Ave	G2	22	55	103	22.5%	**43**	35	31-40	47.4%	1.3%
19	Riley	N 48th St	G1	22	55	98	19.2%	**42**	35	31-40	53.1%	0.0%
20	Riley	Union Rd	G2	20	55	46	10.5%	**45**	36	31-40	43.5%	0.0%
21	Riley	Homestead Rd	G1	18	55	46	21.8%	**47**	37	28-37	34.7%	4.0%
22	Riley	Crooked Creek	G2	20	55	45	42.0%	**46**	39	37-46	52.0%	0.0%
23	Riley	Sherman Rd	G2	16	55	19	23.4%	**39**	32	31-40	57.4%	0.0%
24	Riley	Madison Creek	G2	22	55	16	10.9%	**43**	35	31-40	49.5%	0.0%
25	Riley	Lasita Rd	G1	25	55	18	43.2%	**55**	44	38-47	48.0%	13.8%
26	Shawnee	SW 49th St	G2	24	55	47	21.0%	**42**	34	32-41	45.5%	0.0%
27	Sedgwick	St Louis St	G1	22	**30**	59	9.0%	**27**	21	17-28	75.3%	3.3%
28	Sedgwick	Doris Rd	G1	24	**30**	231	8.3%	**29**	23	21-30	60.5%	9.8%
29	Johnson	W 127th St	G2	18	**35**	49	30.4%	**49**	39	36-45	49.2%	69.4%
30	Johnson	S Gardner Rd	G2	20	**35**	114	13.5%	**40**	33	31-40	52.3%	36.4%
31	Johnson	Moonlight Rd	G2	24	**35**	280	11.4%	**47**	38	36-45	49.7%	70.3%
32	Johnson	143rd St	G2	24	**35**	100	25.4%	**50**	42	36-45	45.3%	77.4%
33	Johnson	S Cedar Niles	G2	22	**35**	73	21.1%	**46**	39	36-45	50.3%	67.1%
34	Miami	231st St	G2	22	55	53	21.4%	**46**	37	31-40	43.8%	2.2%
35	Miami	S Moonlight Rd	G2	22	55	143	16.8%	**47**	39	36-45	46.9%	2.6%
36	Miami	S Cedar Niles	G2	24	55	118	14.7%	**44**	35	31-40	39.8%	1.1%
37	Miami	Columbia Rd	G1	22	55	87	20.0%	**45**	39	36-45	41.9%	1.4%
38	Ellis	Vineyard Rd	G1	22	55	334	15.4%	**58**	48	46-55	41.8%	20.0%
39	Ellis	Buckeye Rd	S	24	55	85	31.1%	**63**	53	51-60	37.1%	40.2%
40	Trego	Golf Course Rd	S	22	55	63	37.1%	**67**	54	49-58	36.1%	46.0%
41	Trego	240th Ave	S	20	55	50	24.8%	**50**	42	39-48	46.4%	4.8%

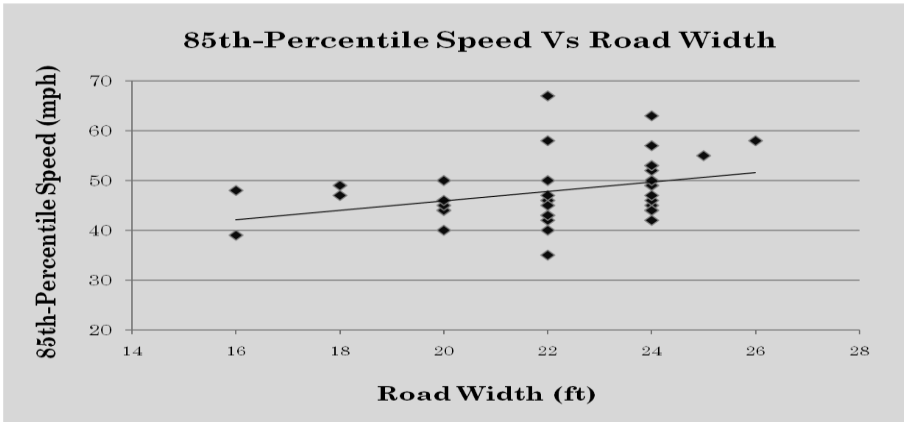

FIGURE 3 Relationship between speed and road width

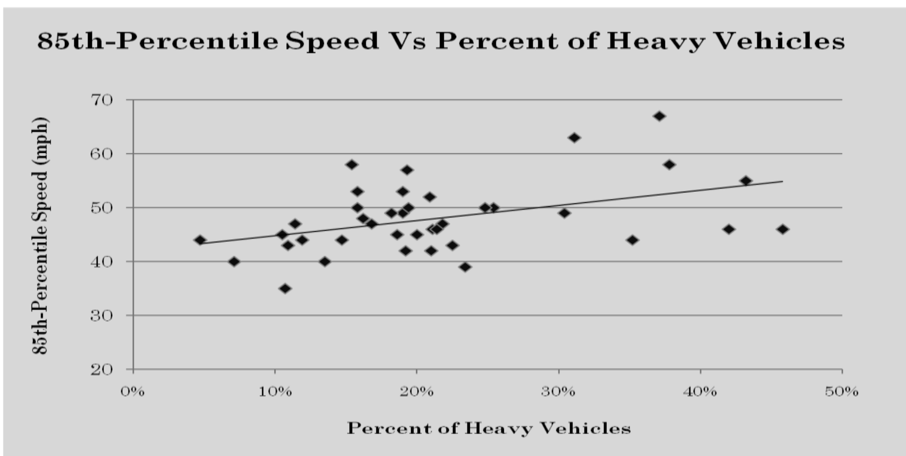

FIGURE 4 Relationship between speed and percentage of heavy vehicles

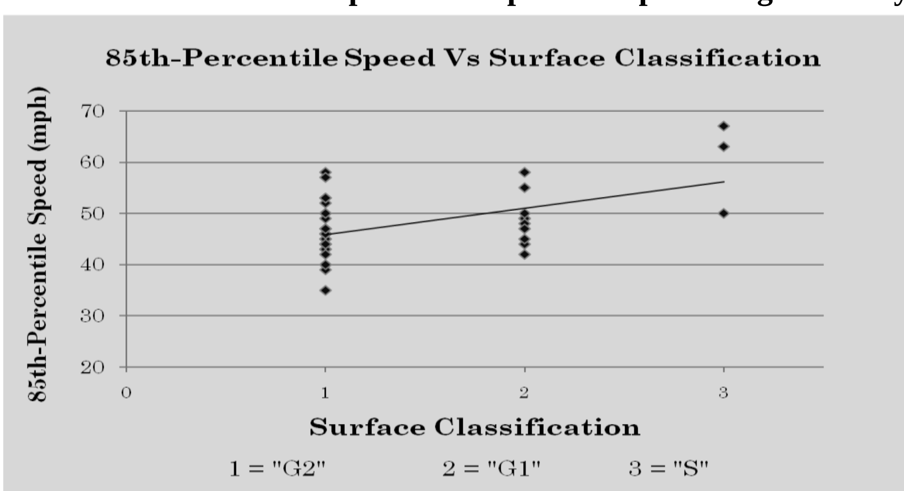

FIGURE 5 Relationship between speed and road surface type

85th-Percentile Speed Model

An 85th-percentile Multiple Linear Regression speed model was also developed to predict the 85th percentile speed by considering six candidate variables. Those are, speed limit, Average Daily Traffic (ADT), road width, percentage of heavy vehicles, surface types and two binary variables to represent three surface types. The estimated model can be used to identify which of the six variables is important on predicting the 85th-percentile speed on gravel roads in Kansas. Table 4 summarizes the estimated parameters and related statistics of the variables that are in the final model. Based on stepwise selection carried out using SAS software, only four independent variables stayed in the final model where ADT and speed limit were not identified as important predictors. This confirmed that ADT and speed limit are not significant enough to affect the 85th-percentile speed of traffic on gravel roads.

Table 4 Variables and Parameter Estimates for the 85th-Percentile Speed Model

Variable	Variable Label	Parameter Estimate	Standard Error	Type II SS	t-value	p-value (Pr > |t|)
Intercept	-	32.733	8.04	378.323	4.07	0.0003
Road Width	RW	1.0114	0.33	209.593	3.03	0.0046
Percentage of Large Vehicles	PLV	16.183	8.28	87.147	1.95	0.0588
Surface Class "G1"	G1	-9.4608	3.22	197.136	-2.94	0.0059
Surface Class "G2"	G2	-12.254	3.06	364.632	-4.00	0.0003
R^2 = 0.5188, MSE = 22.801, Alpha = 0.10						

According, the model for predicting 85th-percentile speed on gravel roads could be written as follows:

$$\mathbf{FFS_{85th} = 32.73 + 1.0114(RW) + 16.183(PLV) - 12.254(G2) - 9.4608(G1)}$$

Where,

FFS_{85th} = 85th-percentile speed (mph)
RW = Road width (ft)
PLV = Percentage of large vehicles in the traffic (decimal)
G2 = Gravel surface classified as "G2" (= 1 if "G2", = 0 otherwise)
G1 = Gravel surface classified as "G1" (= 1 if "G1", = 0 otherwise)

The modeling results indicate that both road width and percentage of large vehicles have direct relationship with 85th-percentile speed on gravel roads. While holding other terms constant, one unit increase in road width (i.e. 1 ft) is likely to cause 85th-percentile speed to increase by about 1 mph. And one percent increase of large vehicles probably causes 85th-percentile speed to increase by about 0.16 mph. The predicted FFS_{85th} can be determined for a sand surfaced road when both G1 and G2 take value "0". The negative coefficients of G1 and G2 indicate that the 85^{th} speed value is greater for sand surfaced roads, which matches with the summary observations given in Table 1. The estimated parameter for G2 implies that, for a given "G2" class gravel road, the 85th-percentile speed on this road is about 12.3 mph lower than that on a sand surfaced road with other conditions being the same. Similarly, a "G1" class gravel road possibly has a 9.5 mph lower 85th-percentile speed than a sand surfaced road. 85th-percentile speed on "G1" gravel roads could be 2.8 mph higher than that on "G2" gravel roads.

SUMMARY AND CONCLUSIONS

This study evaluated various factors affecting the operating speeds on gravel roads, with particular focus on speed limits. Field speed data were collected at number of sites using automatic traffic data counters. Based on the speed data collected, comparisons were made based on various characteristics and simple linear regression models were developed to predict 85^{th} speed and the mean speed of vehicles on gravel roads. The factors looked into and evaluated in this study include surface type, roadway width, speed limit, and percentage of heavy vehicles.

Results of this study indicated that the 85^{th} percentile speeds on gravel roads are affected by surface type, road width, and the percentage of heavy vehicles. Interestingly the speed limit was not a predictor of the operating speeds on gravel roads. Lowered posted speed limit values on gravel roads has not helped in reducing operating speeds, but has increased the number and percentage of speed limit violators. In addition to considering the compliance levels it is also important to pay attention to the additional costs associated with posting and maintaining the speed limit signs at regular intervals. Accordingly, care should be taken in making decisions on reducing the posted speed limits and posting that on gravel roads in the future for new situations.

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